Understanding Root, Tuber and Banana Seed Systems and Coordination Breakdown: A multistakeholder framework

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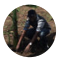

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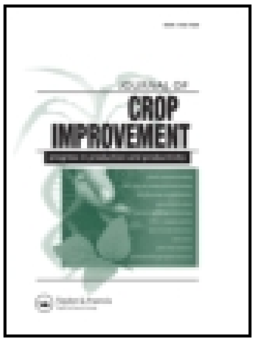

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Understanding root, tuber, and banana seed systems and coordination breakdown: a multi-stakeholder framework

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ABSTRACT

Vegetatively propagated crop (VPC) seed tends to remain true to varietal type but is bulky, often carries disease, and is slow to produce. So VPC seed needs to be handled differently than that of other crops, e.g., it tends to be sourced locally, often must be fresh, and it is less often sold on the market. Hence, a framework was adapted to describe and support interventions in such seed systems. The framework was used with 13 case studies to understand VPC seed systems for roots, tubers, and bananas, including differing roles and sometimes conflicting goals of stakeholders, and to identify potential coordination breakdowns when actors fail to develop a shared understanding and vision. In this article, we review those case studies. The framework is a critical tool to (a) document VPC seed systems and build evidence; (b) diagnose and treat coordination breakdown and (c) guide decision-makers and donors on the design of more sustainable seed system interventions for VPCs. The framework can be used to analyze past interventions and will be useful for planning future VPC seed programs.

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Bananas and plantains; root crops; seed security; seed systems; tuber crops; vegetatively propagated crops (VPC)

Introduction

Seed security is crucial for food security, as is acknowledged by policymakers (Coomes et al. 2015). However, seed systems for roots, tubers, and bananas

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and other vegetatively propagated crops (VPCs) differ from those of crops grown using true seed. Failure to appreciate the differences has often undermined interventions intended to strengthen seed security.

This article presents a multi-stakeholder framework for intervening in root, tuber, and banana seed systems and in other VPCs. These crops are reproduced not with true seed but with vegetative planting material (e.g., roots, tubers, vines, stems, and suckers), called "seed" in this article. Seed systems for VPCs need to be designed differently than those for true seed, and coordination among stakeholders in seed systems is crucial. For example, the failure to appreciate the unique constraints of poorer farmers in Ethiopia led to low adoption of improved seed and new seed technologies (Tadesse et al. 2017). The framework can be used to monitor and correct interventions in VPC seed systems, to identify why such interventions succeed or fail, and to design future interventions more effectively (Sperling, Ortiz, and Thiele 2013).

Some of the world's most important staples are VPCs, including cassava, potato, sweet potato, yams, bananas, and plantains (RTB 2018). Historically, the seed systems of these crops have suffered from low investments, yet in recent years, donors have begun to invest more in VPC seed systems to disseminate new varieties, and to improve seed quality and yields. Results have been mixed, for reasons that are poorly understood.

This framework contrasts seed systems for true seed with those for VPCs. Firstly, VPC seed is bulky and perishable, so it must be multiplied near seed users. Secondly, VPC seed can easily carry pests and diseases, which drive seed degeneration, and requires more quality control to keep seed healthy and protect yield. Thirdly, VPCs tend to remain true to varietal type for generations (i.e., genetic purity is easy to maintain); this is one big advantage for the seed user, but the downside is that farmers may multiply the VPC seed for many years without acquiring fresh seed to flush through diseased stocks. Fourthly, VPCs have low multiplication ratios, so seed production takes longer and is costlier. Finally, VPC seed systems often include a complex division of labor; women and men may play different roles and have different needs as seed producers and users, but these are poorly understood as well.

These contrasts mean that VPC seed systems typically involve a wide range of stakeholders, and coordination among them is necessary to achieve seed security. Coordination within any seed system requires trust among stakeholders (Tripp 2001). Interventions often fail if stakeholders are tugging in different directions instead of communicating and reinforcing each other's roles.

Background, a focus on stakeholders

The multi-stakeholder framework for intervening in root, tuber, and banana seed systems was developed by the CGIAR Research Program on Roots, Tubers and Bananas (RTB) following the core concepts of food security

(Riely et al. 1999) and building on the seed security framework (Remington et al. 2002) and the seed system security assessment (McGuire and Sperling 2016; Sperling 2008). The multi-stakeholder framework for intervening in root, tuber, and banana seed systems allows an analysis of the key seed system functions from the perspectives of all stakeholders, to identify how their different roles mesh together, so that no key functions or players are ignored (Ortiz, Thiele, and Sperling 2013; RTB 2016; Sperling, Ortiz, and Thiele 2013). The elements of the framework are the roles of potential stakeholders, which are systematically compared across the dimensions of availability, access, and quality of seed.

The multi-stakeholder framework for intervening in root, tuber, and banana seed systems

Purpose of the framework

In this article, we show how the multi-stakeholder framework for intervening in root, tuber, and banana seed systems (herein: "the framework") can help to understand VPC seed systems, the different roles of stakeholders and how they relate to each other (potentially conflicting, sometimes collaborating), and how the framework can be used to improve a seed intervention. The framework is presented as a table; the first column lists the stakeholders (groups of people, or organizations) of the seed system. The top row lists the dimensions of the seed system (availability, access and quality), subdivided in action-oriented categories (see RTB 2016; Sperling, Ortiz, and Thiele 2013).

Definitions

A seed system is the network of stakeholders involved in providing, managing, replacing, and distributing the seed of a particular crop in a certain area. In a formal seed system, these components are regulated by the public sector, e.g., standards are set by government; in an informal seed system, the farmers themselves manage these components (Thiele 1999). Formal seed regulation varies by crop and country, typically with some form of inspection known as "certification" to ensure that seed is healthy, free of defects and of a recognized, approved variety. Informal seed systems are predominant, diverse, and poorly documented—although knowledge is growing (e.g., Coomes et al. 2015; Seed System 2017).

Every seed system has its own stakeholders, but for a representative list with key roles, see Table 1. In a perfectly functioning seed system, their roles and visions would be fully aligned, including coordination on what varieties and quantities are needed by whom, timing of supply, information, marketing, regulatory functions, among others. When this does not happen,

Table 1. Key roles of stakeholders of seed systems.

Regulatory agencies	Set policy and law for seed. Define roles in seed production, enforce seed laws, import and export quarantine, accredit seed producers and certification. The authority to inspect seed may be delegated to local levels. Implement emergency measures
Researchers (at national and international centers)	Plant breeders develop new crop varieties. May curate breeder seed and produce early generation seed required to grow certified seed. Other researchers create techniques to manage seed-borne pests and diseases, improve storage, packaging, transport, labelling tools for seed health indexing, quality monitoring techniques, and policy guidelines. Social scientists describe the goals and roles of stakeholders and address other questions, e.g., why varieties are adopted or not
Market traders	Buy and sell seed, usually informal seed, in local markets. They often have other activities as well, e.g., buying and selling food produce
Private sector	Includes agro-dealers and companies that produce or sell seed, often certified seed. They may have a role in estimating seed production requirements
Farmer organizations and associations	Conduct market advocacy (e.g., promoting farmers' produce) and represent seed producers and users to national bodies. Some are also specialized seed producers. Some may also self-regulate for quality
Specialized seed producers	These are not simply farmers who sell some of their produce as seed. They can be organized farmer groups (including women's groups) or individual farmers. They have been trained and use specific techniques to produce seed. Gender differences in access to resources for seed production can be significant
Extension (non-governmental organizations and government)	Teach seed users and specialized seed producers to manage seed. Strengthen farmer groups and distribute planting material. May help estimate seed production requirements
Private food processors	Food manufacturers, supermarkets, restaurants, and others who buy farm produce, add value, and sell it. They act as a stimulus, demanding certain varieties, setting product quality specifications and requiring a stable supply
Seed users	The most important stakeholders, the farmers who demand seed, who accept or reject new crop varieties and who manage most root, tuber, and banana seed on their farms. Women and men often have different needs as users

coordination breakdown can occur. This may mean the particular seed needs of different users are overlooked or ignored. For example, the specific needs of women seed users may go unnoticed by regulatory agencies and specialized seed producers. The dimensions of a seed system (availability, access, and quality) are defined in Table 2.

Method: using the framework to analyze recent interventions

Between December 2012 and September 2015, during five workshops, RTB examined the framework and how to apply it. Case studies were chosen to apply and refine the framework under different conditions, with various crops, in Latin America and Africa. Most of the interventions had just been recently completed. The case studies were written by researchers with

Table 2. Definitions of dimensions of seed systems.

Availability	Supply, the physical existence of seed. Having enough seed at the right place and time.	
Access	Farmers have money or other resources, e.g., by barter, to obtain seed. Access is divided into delivery channel, affordability, and awareness	
	Delivery channel	The distribution and logistics of getting seed from point A to point B. Delivery may be via markets
	Affordability	Farmers can buy the seed at the offered price. As farmers earn more money from a crop they can afford to buy more seed. An intervention can subsidize seed to make it affordable
	Awareness	Information about the benefits of quality seed, where to get it and how (including prices). Agronomic know-how to use seed
Quality	Based on the concepts of (1) genetic quality (including genetic purity, varieties, and biodiversity, e.g., local crop varieties); (2) health: pests and diseases are below specified threshold levels; (3) physiological quality: at the right physiological age—e.g., properly stored in the case of potato and yam or sourced from vigorous and healthy-looking crops for most other VPC (vegetatively propagated crop) seed; and (4) sound physical quality (size, shape and without mechanical damage). Quality is also shaped by acceptability of the seed to users (the users' perception and intended use)	

extensive experience working with the crop and with farmers in the region. The studies were based on publications, project documents, and the authors' personal knowledge of the cases, written to follow a standardized outline based on the framework (Table 3). For more details, see Andrade-Piedra et al. (2016).

The cases included five crops, with three cases in Latin America and 10 in Africa. The interventions ranged from local to multi-national (Table 4). The cases had varying technical goals: for example, managing diseases (cases 10–13), introducing new varieties or hybrids (cases 1, 2, 4–8, 10, and 13), or cheaper or faster multiplication techniques (cases 3 and 7). Sometimes, the crops were produced for sale (Table 4). Some interventions organized much of the delivery themselves and others strengthened existing structures (Table 4).

Results

Seed availability

Most cases tried to improve seed quality and increase availability. For example, in Malawi, where a formal seed potato system barely existed, the intervention sought for nine years to build one. The intervention introduced six new varieties that were multiplied by a government agency and a snack food manufacturer, using aeroponics (plants are grown in an enclosed irrigated space with their roots in the air) to produce high-quality seed for farmer groups, trained by extension to multiply and sell the new seed. The project was designed to provide groups with small quantities of seed. However, farmers expected the project to provide them with more seed than was possible. The snack food company stopped seed production when

Table 3. Case studies of seed systems (Andrade-Piedra et al. 2016).

Crop and location	Case study (intervention)	Main focus
1. Potato, Ecuador (Kromann, Montesdeoca, and Andrade-Piedra 2016)	CONPAPA (Consortium of Small Potato Producers)	A local farmers' organization produces quality declared potato seed for accessing high-value markets
2. Potato, Peru (Orrego and Andrade-Piedra 2016)	Aeroponic seed potato in Cajamarca	Clean potato seed with native varieties reintroduced to the communities
3. Yam, Nigeria (Odu, Coyne, and Kumar 2016)	AYMT (Adapted Yam Minisett Technique)	Researchers improve an on-farm technique for planting more land with less seed yam
4. Banana and plantain, Ghana (Jacobsen and Dzomeku 2016)	TARGET (Technology Advancement for Rural Growth and Economic Transformation)	Researchers shared new hybrids with farmers
5. Sweet potato, Tanzania (Ogero, McEwan, and Pamba 2016)	Marando Bora ("Better Vines")	Delivering local and improved varieties, producing clean seed off-farm, managing vines on-farm
6. Sweet potato, Rwanda (Nshimiyimana et al. 2016)	Rwanda Superfoods	Similar to case above, with a sweet potato processor who required a consistent supply of roots
7. Potato, Kenya (Atieno and Schulte-Geldermann 2016)	Three generations (3G)	Disseminate new varieties and clean seed with rationalized regulations permitting quality declared seed
8. Cassava, Nicaragua (Ospina 2016)	CLAYUCA (Consorcio Latinoamericano y del Caribe de Apoyo a la Investigación y al Desarrollo de la Yuca)	New varieties for cassava awaken government and farmer interest, in response to demand by agro-industry
9. Potato, Malawi (Mudege and Demo 2016)	Enhanced potato productivity	Project released new varieties, trained farmers to produce seed, with equal participation of men and women
10. Cassava, Africa (Okechukwu and Kumar 2016)	UPoCA (Unleashing the Power of Cassava in Africa)	Disseminating new, disease-resistant varieties in seven African countries
11. Banana, East Africa (Kikulwe 2016)	Tissue culture (TC) banana	Helping to establish nurseries where communities can harden tissue cultured bananas to sell to farmers
12. Banana, East Africa (Jacobsen 2016)	C3P (Crop Crisis Control Project)	A new multiplication technology and training to help farmers manage a new crop disease
13. Cassava, East Africa (Walsh 2016)	GLCI (Great Lakes Cassava Initiative)	A cassava initiative in the Great Lakes region of Africa especially in response to widespread cassava disease

the firm changed ownership. A coordination breakdown followed, as frustrated farmer groups were not able to get enough seed to meet their demands (Mudege and Demo 2016).

Table 4. Scale of interventions, seed delivery channels, and seed users' market orientation.

Case study and crop	Scale†	How seed was delivered during intervention	Use of farm produce
1. CONPAPA (Consortium of Small Potato Producers) (potato)	Local	By a farmers' organization, strengthened by the intervention	Mostly for sale, e.g., to restaurants
2. Cajamarca (potato)	Local	By a farmers' organization organized as seed producers by intervention	Home use, some sold to supermarkets
3. AYMT (Adapted Yam Minisett Technique) (yam)	Local	On-farm and local distribution	Home use and sale to traders
4. TARGET (Technology Advancement for Rural Growth and Economic Transformation) (banana and plantain)	Local	By intervention partners	Sale to traders and home use
5. Marando Bora (sweet potato)	National	Clean seed from government through commercial growers to small groups (including women) to grow and distribute seed	Mostly home use
6. Superfoods (swee tpotato)	National	From government stations, delivered to local farmer groups	Home use and some sale (e.g., to biscuit maker)
7. Three generations (3G) (potato)	National	First generation on large farm, later generations reared on smaller commercial farms, shared with farmer groups trained by intervention	Mostly sold to traders
8. CLAYUCA (Latin American and Caribbean Consoirtium for the Support of Cassava Research and Development) (cassava)	National	New varieties initially screened by government, later shared with farmers by food manufacturers	Home use, sale to traders, increasing sale to manufacturers
9. Enhanced potato productivity	National	By government and a food manufacturer. Seed shared with farmer groups trained by intervention	Mostly sale to traders
10. UPoCA (Unleashing the Power of Cassava in Africa) (cassava)	Multi-national	From community seed plots, facilitated by the intervention	Home use and sale to traders
11. Tissue culture (TC) banana	Multi-national	By community level seed producers, organized by the intervention	Sale to traders and home use
12. C3P (Crop Crisis Control Project) (banana)	Multi-national	Intervention trained farmers in new seed techniques	Sale to traders and home use
13. GLCI (Great Lakes Cassava Initiative) (cassava)	Multi-national	From community seed plots, facilitated by the intervention	Home use and sale to traders

†Local: Several communities, often in a single district. National: In several districts, often the main part of the country that produces the target crop. Multi-national: An intervention in two or more countries.

Seed access

Delivery channels

None of the cases studied aimed at improving delivery through local markets and traders, not even Peru where informal channels were well described (e.g., De Haan et al. 2010; Urrea-Hernandez, Almekinders, and Van Dam 2015). Projects preferred to organize farmers into new delivery channels; e.g., GLCI multiplied cassava seed in community plots (Walsh 2016), as did the UPoCA project (Okechukwu and Kumar 2016). Only one case included a large private sector seed multiplier, and that was for potato seed, which generally has more commercial demand and the seed commands a high price. With hybrid crops, private sector entry into seed systems is more feasible, whereas for roots, tubers, and bananas, in general, subsidy elements tend to prevail (Gaffney et al. 2016).

Marando Bora ("Better Vines") was a project designed to distribute healthy sweet potato seed to 150,000 farmers in Tanzania (Ogero, McEwan, and Pamba 2016). The project tested the development of a commercial sweet potato seed system, providing training, inputs (irrigation equipment, starter material), stimulating demand (with subsidized vouchers, and sharing information), and targeting mothers of young children to produce biofortified orange-fleshed and white-fleshed varieties to improve food security and nutrition.

Sweet potato was largely a women's crop, and a gender analysis recommended that the project should only support women to become specialized vine multipliers. In a compromise reached with the largely male staff of NGO partners and extension services, the project trained both individual (75% male) farmers to produce sweet potato vines and also identified existing farmer groups with many female members to become specialized seed growers. The individual and group multipliers sold their vines to other farmers, in exchange for subsidized vouchers. The vine growers multiplied improved varieties with virus-free seed from research centers, although some susceptible varieties became re-infected after two seasons in the field. The NGOs trained and facilitated farmer groups, although some NGOs could not keep up with all of their groups (Table 5).

Some NGOs thought that the subsidies might undermine existing markets for vines. Subsidies can make seed affordable, but they can also crowd out existing seed producers (Spielman and Smale 2017). The voucher system was burdensome for the NGOs, seed producers, and farmers, and the decentralized vine multiplication approach could not be scaled quickly enough to reach all targeted beneficiaries. In the second year, partners found other innovative ways to reach more beneficiaries, e.g., using schools as vine distribution points. Medium-scale multipliers also produced vines that were distributed free of cost at central points. An analysis of the project using the framework indicates that the coordination failures were as follows: (1) seed production was not always timed to match peak demand for vines in context of unpredictable rainfall patterns, 2) inability to maintain quality as seed production and dissemination were scaled in attempt to reach 150,000 beneficiaries in just two years, and (3) in the limited time of the project, there was a failure to institutionalize linkages among stakeholders in the seed system.

Affordability

Marando Bora used vouchers to subsidize seed for farmers. Farmers can also afford more seed if it is profitable to use (if smallholders earn more for the

Table 5. Roles of the Marando Bora ("Better Vines") case, sweet potatoes in Tanzania.

		Access			Quality	
Stakeholder	Availability/supply	Delivery channel features	Affordability/ profitability issues	Info to create awareness and demand	Genetic quality (incl. biodiversity)	Health, physiological, and physical quality
Local government decision makers	Project staff attended district council meetings to advocate for greater investment in sweet potato seed systems			Explained importance of intervention to local leaders, who also participated in field days and demos		
Regulatory bodies						Pilot of community-based inspection scheme led to dialogue with Tanzanian authorities on seed standards for sweet potato, gazetted in 2017
National research		Bred 2 varieties, released 2 land races. Sent material to Kenya for clean-up				Pathogen testing
International research	CIP (International Potato Center) led the project, to make seed available to farmers at low cost	Project partners identified and trained individuals and groups to multiply seed	Project subsidized the cost of the seed with vouchers		Provided new varieties. Cleaned up land races. Accelerated release of varieties under EAC (East African Community) harmonization policy	KEPHIS (Kenya Plant health inspectorate Service) conducted clean-up and together with a private tissue culture lab supplied pathogen tested starter material
Private seed sector	Private tissue culture lab produced the starter tissue culture plantlets	Private medium-scale multipliers produced seed, esp. 2nd year				Private lab received clean seed from KEPHIS for *in vitro* multiplication.

(*Continued*)

Table 5. (Continued).

Stakeholder	Availability/supply	Access			Quality	
		Delivery channel features	Affordability/ profitability issues	Info to create awareness and demand	Genetic quality (incl. biodiversity)	Health, physiological, and physical quality
Farmer groups	Project partners identified existing farmer groups (majority women) to be trained to produce seed	Distributed to seed users in exchange for subsidized vouchers		Project trained group leaders. Branding and communication materials provided, but late		Piloted use of net tunnels to rear clean seed
NGOs (non-governmental organizations)	NGOs were project implementing partners	NGOs trained and farmer groups to multiply and distribute seed	Managed vouchers	Shared information through posters, radio, etc.		Trained seed growers to manage pests and diseases. Pilot community seed inspection scheme
Seed users	Existing lack of seed at start of rainy season	Often lived in same village as seed producers	Paid part of cost	Project targeted women with children under 5 years	Previously had limited access to improved varieties	Existing: high incidence of sweet potato virus and weevils

produce they sell, they will have more money for seed). In the following example from Ecuador, the framework helps to identify how a bottleneck in seed certification was resolved by understanding the farmers' perspectives.

CONPAPA (Consortium of Small Potato Producers) is a farmers' organization in highland Ecuador, established to connect smallholders to their buyers and to urban consumers (Kromann, Montesdeoca, and Andrade-Piedra 2016). Across many years, researchers helped CONPAPA create links with buyers of ware (table) potatoes. Those new links and expanding demand for potatoes from the cities allowed farmers to sell better potatoes at higher prices and in greater volumes. Expanded sales allowed farmers to afford seed, but not certified seed, which was often in short supply. In 2010, for example, the retail price of certified potato seed was $0.70 per kilo, but QDS (quality declared seed) from CONPAPA sold for just $0.42, whereas ware potatoes sold to restaurants fetched $0.28 (Kromann, Montesdeoca, and Andrade-Piedra 2016). Smallholders in CONPAPA organized themselves to buy high-quality source seed from Ecuador's National Agricultural Research Institute (INIAP), plant it and produce their own QDS, which they sold to seed users. Seed producers (members of CONPAPA) received training and collaborated in quality control visits with CONPAPA technical staff, who identified plant health problems, and counseled farmers on how to improve quality. The CONPAPA experience influenced the Ministry of Agriculture to change the quality control guidelines for certified seed, to allow for QDS. Farmers were trained and began producing QDS seed before there was a standard for it under Ecuador's seed rules and regulations. Thus, CONPAPA increased the affordability of seed by setting a new, lower-cost seed quality standard, building the capacity of seed producers to comply with that standard, and influencing the recognition of that standard through public policy.

A potential coordination breakdown was avoided by aligning stakeholders through communication. Seed regulatory agencies want to ensure that farmers get good quality seed, which the farmers also want but cannot afford if certification increases the price too much. The Ministry and CONPAPA were able to resolve this difference, and make seed more affordable, through collaboration to lower regulation costs by allowing seed to be inspected for quality, rather than certified (Table 6). Other stakeholders connected seed users to new, better-paying markets for ware potatoes, increasing incomes, which allowed farmers to afford seed.

Awareness (sharing information)

The Ecuador potato intervention described earlier made a long-term effort to share information between producers and buyers, e.g., about quality control and the advantages of the new seed (Kromann, Montesdeoca, and Andrade-Piedra 2016). The Kenyan potato case (7, in Table 3), presented here, also

Table 6. Roles of the CONPAPA (Consortium of Small Potato Producers) case, potato in Ecuador.

	Access				Quality	
Stakeholder	Availability/supply	Delivery channel features	Affordability/profitability issues	Info to create awareness and demand	Genetic quality (incl. biodiversity)	Health, physiological, and physical quality
Regulatory bodies			Allowed farmer to produce QDS (quality declared seed)			Used quality criteria from CONPAPA to set new seed standards
National research	Developed and released varieties. Provided certified seed	An earlier project forged links between farmers and other stakeholders				
International research				Supported multi-stakeholder platforms		Facilitated policy change for QDS
Farmer organization (CONPAPA)	Set production plans of QDS	Bought certified seed. Organized sales of QDS to farmers	QDS lowered price of seed	Promoted commercial varieties	Provided quality control	Made standards more realistic
NGOs (non-governmental organizations)		Bought seed from CONPAPA		Helped share info between actors		
Private sector processors				Stimulated demand for constant supply	Stimulated demand for varieties	Demanded quality (e.g., size, health)
Seed users			Women, indigenous farmers could afford QDS seed		Demanded the varieties offered	Demanded high-quality seed

shared information, training 20,000 farmers to use the new seed and keep it healthy (Atieno and Schulte-Geldermann 2016). The training included demonstration plots, field days, and FM radio broadcasts in vernacular languages. Extensionists encouraged farmers to buy clean seed from specialized producers, and then produce the seed themselves for one or two generations using techniques like positive selection (choosing seed in the field from the healthiest plants) and negative selection (eliminating unhealthy plants) (Atieno and Schulte-Geldermann 2016). Extension explained the advantages of new potato varieties to farmers, avoiding a coordination breakdown of differing varietal preferences for seed purchase between seed users and specialized seed producers.

The Kenyan intervention also helped to adjust regulations for seed potato and helped public and private seed producers to invest in aeroponics. Certain commercial farmers were trained to buy the mini-tubers from the aeroponics units, to grow another two generations of clean seed in open fields, greatly increasing the supply (and lowering the cost) of seed. This new seed found a ready market because 20,000 seed users now had fresh information about where to buy the new seed and how to use it profitably. More than half of the farmers trained were women, many of whom could now afford QDS for the first time (Atieno and Schulte-Geldermann 2016).

Seed quality

Genetic quality, varieties, biodiversity, and genetic purity

Varieties. Emerging virus diseases are difficult to manage without resistant crop varieties. Cassava mosaic disease and other viruses are serious pests in Africa. Starting in 2008, the UPoCA (Unleashing the Power of Cassava in Africa) project shared 59 new virus-resistant cassava varieties with >11,540 smallholders in seven countries. The project contracted commercial farms to grow the source seed.

In a clean seed intervention, such as the sweet potato in Tanzania or Kenyan potato cases described earlier, the projects often encourage some stakeholders to become permanent seed producers. This enables clean seed to flow through the system constantly and flush out the crop disease(s). But an intervention like UPoCA, based on virus-resistant varieties, needs only produce the seed for a short while. The commercial farms could be contracted for one season. Cassava is grown for its starchy roots, whereas the seed is an inedible stem. Researchers allowed commercial farmers to keep all of the valuable roots, but give some of the stems to the project. The stems were distributed to 290 community nurseries to multiply stems, which the seed users could then try, multiply on their own farms, and pass on to neighbors (Okechukwu and Kumar 2016). This two-year project was able to avoid a coordination breakdown and secure wide-scale adoption of new crop varieties by setting up an ephemeral seed system based on commercial seed producers, who supplied community nurseries. Because the farmers could then multiply the virus-resistant seed for themselves, there was no need to build a complex, long-term seed system.

Biodiversity. While a seed intervention often introduces varieties, it can help preserve local varieties (see yam in West Africa: Odu, Coyne, and Kumar 2016). For example, in Peru, the intervention re-introduced purple and red-fleshed native varieties that farmers had lost (Orrego and Andrade-Piedra 2016).

Genetic purity. This is more of an issue in grains than in VPCs because their clonal seed generally multiplies true to type. However, some cassava plots are planted to a mix of genotypes, which farmers may even consider to be the same variety.

Seed health

Poor seed health is linked to seed degeneration or to rapid and devastating losses usually caused by emerging pathogens. Emerging pests and diseases can be managed by quarantine or by host eradication. Thomas-Sharma et al. (2015) proposed managing degeneration with a combination of plant resistance, clean seed, and on-farm management (positive or negative selection, crop rotation, chemical control, etc.). The interventions considered here (Andrade-Piedra et al. 2016) tried all of these tactics (Table 7).

Clean seed was by far the preferred tactic for managing seed health (Table 7). In at least nine of the case studies in which seed degeneration was a concern, on-farm management was an option for improving seed health, as in Kenya, where farmers were taught to do positive selection and negative selection to keep their seed healthy (Atieno and Schulte-Geldermann 2016).

Clean seed is used, especially when there is no resistant variety, or when resistance is only partial. Producing clean seed usually involves some high technology (such as tissue culture for bananas, cassava, potato and sweet potato, or aeroponics for potatoes), and a network of multipliers to produce the final seed, preferably in low-pest areas. Keeping seed healthy in open fields is a challenge for VPCs, which are slow to multiply.

Physiological and physical quality

Seed potatoes are typically smaller than ware (food) tubers, to reduce the amount of seed needed per hectare. Smallholders usually sell (or eat) the bigger tubers and plant the smaller ones, but specialized seed producers often use a specific technique (such as dense planting) to grow small tubers. If the potatoes cannot be sold as seed, they are difficult to sell as ware: an added

Table 7. Seed health constraints and management tactics.

		Management tactics				
Case study	Seed health constraint	Quarantine	Host eradication	Host resistance	On-farm management	Clean seed
CONPAPA (Consortium of Small Potato Producers)	Black scurf (*Rhizoctonia solani*), Andean weevil (*Premnotrypes vorax*)				Yes	Yes
Cajamarca (potatoes)	Late blight (*Phytophthora infestans*), Andean weevil					Yes
AYMT (Adapted Yam Minisett Technique)	Nematodes (*Scutellonema bradys* and *Meloidogyne* spp.), fungi (*Botryodiplodia* sp.,*Fusarium* sp.), several insects			Yes	Yes	Yes
TARGET (Technology Advancement for Rural Growth and Economic Transformation) (bananas and plantains)	Sigatoka (*Mycosphaerella fijiensis* and *M. musicola*), nematodes, weevils (*Cosmopolites sordidus*), BSV (Banana Streak Virus)			Yes	Yes	Yes
Marando Bora (sweetpotato)	SPVD (sweetpotato virus disease)			Yes	Yes	Yes
Superfoods (sweetpotato)	SPVD			Yes	Yes	Yes
3G (Three generations) (potato)	Viruses: Potato leaf roll virus (PLRV), potato virus Y (PVY); bacterial wilt (*Ralstonia solanacearum*)			Yes	Yes	Yes
CLAYUCA (Latin American and Caribbean Consoirtium for the Support of Cassava Research and Development)	Mentioned in passing					Yes
Enhanced potato productivity	Late blight, bacterial wilt, blackleg (*Erwinia carotovora*), PLRV, tuber moth (*Phthorimaea operculella*), rootknot nematodes (*Meloidogyne javanica*)			Yes	Yes	Yes
UPoCA (Unleashing the Power of Cassava in Africa)	CMD (cassava mosaic disease)			Yes	Yes	Yes
Tissue culture banana	Banana Xanthomonas wilt	Yes	Yes		Yes	Yes
C3P (Crop Crisis Control Project) (banana)	Banana Xanthomonas wilt	Yes	Yes		Yes	Yes
GLCI (Great Lakes Cassava Initiative)	Cassava mosaic disease (CMD), cassava brown streak disease (CBSD)	Yes		Yes	Yes	Yes

risk for specialized seed producers. This illustrates the need for trust or close collaboration between seed producers and users, as in the Kenyan and Ecuadorian seed cases, reviewed earlier (Atieno and Schulte-Geldermann 2016; Kromann, Montesdeoca, and Andrade-Piedra 2016). Shape is also important for some crops, especially potato, because some viruses distort parts of the plant, including the seed.

Potato and yam seed go through a dormancy period, so the seed must be aged. In potato, the physiological age of the tuber affects the number of sprouts, plant growth, and yields (Struik and Wiersema 1999). Most other VPC seed must be sourced from a growing, vigorous and healthy crop, not from juvenile or old plants. A pronounced dry season can interrupt the availability of seed. In the case of sweetpotato in Tanzania (Case 5, Table 5) farmer groups produced their vines in irrigated seed beds during the dry season, to sell at the start of the rains. Specialized seed growers can develop a business by meeting the need for physiological and physical quality of seed.

Rapid multiplication techniques

Rapid multiplication techniques (RMT) may fail if the capital and technical requirements are too difficult for stakeholders. The C3P (case 12, Table 3) was a project in six East African countries from 2006 to 2008, in response to the emerging banana bacterial wilt problem. The proposed technique, macropropagation of banana plantlets, required farmers to learn multiple new tasks: paring to remove roots, boiling water to eliminate nematodes from suckers, peeling to expose axillary buds, destroying the apical meristem to stimulate shoot development, sterilizing substrate, managing the humidity chamber, rooting, and hardening. While macropropagation was a pilot technique, it was too complicated, expensive, and labor-intensive for farmers to use. During the project, researchers observed that some farmers simply destroyed stems with symptoms, instead of uprooting the entire mat, as advised by the project. Symptomless stems from diseased mats still yielded edible bunches. Farmers were also observed using symptomless suckers as a source of planting material. After the project ended, further studies demonstrated that symptomless banana suckers sourced from infected fields were indeed a viable alternative for seed within infected banana gardens (Sivirihauma et al. 2017). This was a clear coordination breakdown between researchers and farmers, where the researchers were unaware of valuable local knowledge of how the disease spread, and where farmers were expected to use overly complex seed reproduction technology. Projects are often drawn to high-technology RMTs, and unrealistically expect these innovations to be used by farmers. Successful cases often relied on a more appropriate technology (such as community seed plots for cassava) and on already established specialized seed producers (such as CONPAPA, in Ecuador).

Regulatory bodies

It is a challenge for the public sector to certify seed in a cost-effective and affordable way, but alternatives, such as QDS (quality declared seed), usually need to be agreed with certification authorities to be legally used. Under a massive disease constraint, the Great Lakes Cassava Initiative (GLCI) innovated a "small is beautiful approach" of producing seed on thousands of decentralized, half-hectare plots, which distributed small amounts of seed to farmers. This was only feasible because of QDS, which involved lab testing for some early generation seed fields and physical inspections in thousands of cassava fields.

Nearly all countries have some regulations for VPC seed, although enforcement may be difficult to implement. Several case studies showed that interaction between stakeholders (e.g., project staff, seed producers, and regulators) led to regulations that were better adapted to VPCs. In Ecuador, a 2012 ministerial agreement established new protocols for producing certified seed potatoes, based on protocols pioneered by organized farmers (CONPAPA), where internal inspections helped farmers to learn improved methods for preventing disease in the field and storage (Kromann, Montesdeoca, and Andrade-Piedra 2016). The banana tissue culture project offered training for farmers to meet regulations and helped to sensitize regulators via meetings, and presentations (Kikulwe 2016). The GLCI introduced internal quality control for cassava seed producers in villages; coordination breakdown was avoided with meetings and workshops with project staff and regulatory agencies (Walsh 2016).

Discussion

Stakeholders

Gender influences seed security. Women smallholders may have less cash to access seed, and different demands for varieties, volumes, and time of provision. Failing to see these differences and the key roles of women can lead to coordination breakdown and may limit their access to seed, threatening their families' incomes and food security. Several of the cases (e.g., C3P, GLCI, Marando Bora) made a great effort to target women. A gender-sensitive project design could be improved by using the framework.

Researchers often build on ties forged between extension and farmers to introduce new crop varieties to communities. Extension may even help farmers to form seed producer groups. Researchers often expect extensionists to mentor the seed producers, link them to customers and train seed users. If mandates are not clearly stated, or if extension is not fully trained and funded to do this demanding work, there may be coordination breakdowns between extension and research and donors over project results.

Once specialized seed producers start selling seed, they may come under scrutiny of regulatory agencies, which can be grounds for conflict, because stricter standards increase production costs. The level of regulation should be an economic decision. Policymakers and designers of seed systems should ask: what is the added value of quality and what would be the cost benefit of certification? Because VPC seed is bulky and produced on many small farms, it is more expensive to inspect than true seed, placing greater demands on seed inspectors. Sensitive engagement between regulators and seed producers can help to rationalize VPC seed regulations around an economically viable level of quality control.

To identify and mitigate potential conflicts between actors in a VPC seed system, planners of an intervention should make an explicit inventory of the main bottlenecks (of availability, access and quality) and how those are related to the stakeholders using the framework (see RTB 2016). Seed system interventions will benefit from visualizing conflicting interests among stakeholders. Sustainable solutions can best be reached if it is clear who is benefitting the most from support or subsidies, or suffering the costs of regulations.

Availability, access, and quality

As with food security, seed security often depends on access and quality more than on mere availability. VPC seed is usually available, but farmers may not have access to seed of the right quality and desired quantity at the appropriate time. Interventions often try to improve access to certain types of VPC seed (e.g., new varieties, or clean seed) by using RMT (e.g., aeroponics and tissue culture). It can be a challenge to find the right stakeholders to use these techniques. Seed producers must be confident of the future market or they will not continue to use RMTs. Better resourced organizations and individuals (i.e., larger-scale, and male farmers) are often the most able to use these capital-intensive technologies. A successful experience with RMT usually depends on coordination between several stakeholders, especially extension, to share information with farmers about using the seed.

Affordability is key to seed access. Many smallholders are women, often with a limited seed budget, or who normally access seed through social networks. Interventions often assume unreasonably high farmer demand for new seed. Smallholders may need only small amounts, especially because VPC seed can be multiplied on-farm. Farmers may buy small amounts of VPC seed to acquire a new variety (Jacobsen and Dzomeku 2016; Okechukwu and Kumar 2016; Ospina 2016; Walsh 2016). Farmer demand can only sustain a specialized seed enterprise when farmers are unable to store or produce the seed themselves, if there is strong commercial demand for the farm produce, or if the seed supply is interrupted by extended dry season, drought, pests, and diseases.

Part of seed quality is distributing the varieties that stakeholders want. New varieties can be chosen with direct participation from stakeholders, e.g., asking what colors, cooking qualities, and other traits are desired, but sometimes key stakeholders have different and contradictory goals. Breeders may be targeting resistance to a pest or disease that has not yet arrived, whereas farmers are looking for a fast-growing variety. Systematic use of the framework can capture such differences and lead to negotiated solutions.

In areas with high biodiversity, the local regulations usually still do not consider native varieties. This places regulators in a potential conflict with any stakeholder who is trying to distribute seed of native varieties, unless the regulations are modified to recognize these varieties. For example, in Peru, of the more than 4000 native potato varieties, just 60 are registered with the government. So strictly speaking, it is illegal to sell seed of the unregistered varieties, although a new regulation is being discussed in Peru to allow seed of unregistered native varieties to be sold (INIA 2015).

Conclusions

The multi-stakeholder framework for intervening in root, tuber, and banana seed systems is valuable for assessing seed systems relative to availability, access, and quality. The framework's focus on stakeholders also allows it to be used to anticipate and mitigate potential conflicts between/among stakeholders. The framework helps to reveal some of the assumptions of seed system practitioners and policymakers. While the framework has been used to describe seed interventions in the recent past, it can also be used to structure background studies and design future interventions, especially for donors and policymakers.

Root, tuber, and banana seed is usually available before an intervention, but quality and quantity may be an issue for some farmers. The new seed provided by VPC seed intervention is often subsidized or given away to make it affordable. Nearly all farmer groups that are set up as seed producers require subsidized equipment and subsidized management in the form of NGO staff members, who train the farmers and help them establish their enterprises. Interventions tend to create alternative delivery systems rather than working with existing market traders, which may be a challenge for longer-term sustainability.

The new seed often meets farmers' demands for quality, even if the intervention does not start with an explicit study of the system. However, seed of susceptible varieties may become re-infected soon after it is cleaned of disease.

Clean seed for small farms can be a missed opportunity, unless local communities are fully involved to implement on-farm management practices locally.

The seed interventions reviewed here often did link different stakeholders in mutually beneficial ways. For example, farmers got useful new varieties from plant breeders, and farmers sold produce to output markets. Some of the new seed multiplication techniques were more appropriate for large, commercial farms, but some of the technical innovations (e.g., community cassava gardens, and positive seed selection) could be used by smallholders.

The use of the framework across multiple crops and countries also highlighted key areas for further refinement, e.g., ensuring an integrated gender analysis of seed system because even within one type of stakeholders, men and women may have conflicting interests. By using the framework in the future, seed interventions may be able to link with the appropriate actors in existing seed markets, and understand the potentially conflicting roles of different stakeholders.

Critical areas for coordination among stakeholders, to avoid coordination breakdown, include the following:

- *VPC seed producers and users*, because VPC seed may not be easily stored and physiological age needs to match planting date. Policymakers must set different standards and procedures for VPC seed (e.g., more local production, more education for seed users, and more capacity building for seed producers).
- *Regulatory agencies* see the disease risk in VPCs, but typically base quality control practices on standards applicable to true seed that can be produced at a central, easily supervised location. When applied to VPCs, these are not cost effective, especially if government services are relatively weak.
- *Donors and national agencies* seek to promote broader adoption of new varieties and to improve seed quality. However, there has been a lack of clarity of how to do this in a commercially sustainable way, in particular for seed multiplication.

To improve VPC seed systems, the array of stakeholders noted earlier would need to come together with a shared vision of complementary roles and common goals. The multi-stakeholder framework proposed here is a tool to (a) document VPC seed systems and build a stronger evidence base for future interventions, (b) diagnose coordination breakdown and recommend solutions, and (c) guide design of more integrated and sustainable seed system interventions for VPCs.

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